Towards self-organizing production environments

W kierunku samoorganizujących się środowisk wytwórczych

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DOI: https://doi.org/10.17814/mechanik.2017.7.63

The paper illuminates the software-technical innovations in automation industrial equipment presented at the Hannover Messe 2017: the new idea of Industry 4.0, Internet of things, smart factory, communication via field buses, co-bots, industrial communication.

KEYWORDS: F, Industry 4.0, smart factory, Internet of things, industrial automation, co-robots, fieldbuses

At Hannover Messe 2017 (organized for the 60th time), which took place on 24–28 April, 6,500 exhibitors from all over the world presented. More than 60% of companies came from outside Germany. The fair was visited by a record number of visitors – 225,000. As many as 30% of them came to Hannover from abroad.

Apart from traditional presentations at the exhibition stands, nearly 1,500 scientific and technical papers and dissemination lectures were given. This year, Poland was the partner country of the fair, which allowed to present the offer of more than 200 domestic companies.

The keynote of this year's edition was: "Intelligent technologies have a positive impact on the growth of the industrial market." The fair was divided into six thematic areas:

- automation components – robots, cobots, manipulators,
- drives and controls,
- digital factory – IT integration,
- energy – generation, storage and transmission,
- compressed air and vacuum technology,
- component supply chains.

In spite of difficult situation in the industrial automation sector in 2017, the turnover is expected to grow by at least 1.8%, which was a positive stimulus and encouraged both exhibitors and visitors to participate actively in the event. Of many themes and issues discussed, one can definitely formulate some of the themes that are now considered crucial for development. They were:

- services related to the efficient analysis of large amounts of data in cloud systems,
- growing importance of various software applications,
- focus on efficient data transfer systems (especially those offering full time determinism),
- use of artificial intelligence in manufacturing (data processing, inference, control),
- wide use of collaborating robots.

Mobile machine tools

In traditional terms, machine tools and technological machines have fixed locations in the production hall. Workpieces are delivered/transported to suitable machining sockets. For objects of relatively small size and not too much weight, this approach is justified. However, when machining large components (for the aviation industry, wind turbines, etc.) and their heavy weight, transportation becomes a complicated task, requiring a lot of effort and space.

Researchers from IFW (Hannover University) have proposed a new concept. It involves the use of machine tools moving to the workpiece as the next machining task is completed. The machine's kinematics are based on, for example, five control axes (three linear and two rotary). To increase power, dual motors are used in linear drives. Such a machine tool (fig. 1) will be equipped with a variety of tools, extensive sensory systems, dedicated control software and specialized algorithms to maintain the required machining accuracy. All components will, of course, be compatible with the Industry 4.0 concept. It is anticipated that such devices will be used in such technological processes as measuring, grinding and machining (drilling, milling).

Fig. 1. Concept model of Picum One mobile milling machine [1]

PLC controllers

Interesting activities – in the spirit of the Industry 4.0 concept – are made in the area of traditional PLCs. This group of automation devices is still the most commonly used in the industry – especially at the production hall level. Due to the increasing flow of data – collected by increasing numbers of sensors, actuators and class IIoT devices while using standard means of communication – transfer of relevant information to processing centers located in the cloud environment (outside the plant) can be a real obstacle (bottleneck) in introducing the concept of digital factory. To remedy this, Omron proposes extending the traditional PLC (fig. 2) by adding artificial intelligence (advanced algorithms) to replace the

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knowledge and intuition of qualified engineers and increase the amount of data processed locally (in the controller) without referring to the cloud. It is noteworthy that this approach allows for free processing of data (vibration, position and temperature) collected in millisecond periods. The analysis and use of these combined data make it possible to predict machine/tool/process errors and effectively prevent downtime and deterioration in the quality of the final product.

Fig. 2. Family of the latest Omron PLCs [2]

Built-in intelligent algorithms are designed, for example, to learn repetitive movement of devices with precise measurements. This is possible through the use of feedback for real-time monitoring and control of the machine. An example of how the controller works is as follows:

1. Acquisition of measurement data (acceleration, voltage, etc.) and process data (machining parameters, tools, etc.), time indexing and elaboration of structured data.
2. Regular or occasional generation of data sets that are instantaneous images of the machine and process.
3. Based on aggregated data, create a digital model of the machine using causal analysis (cause-effect).
4. Sending to supervisory systems the results of calculations that make up the updated process model.

Internet of things (IoT/IIoT)

So far, there is not the only one universally accepted definition of the phenomenon of the Internet of Things or the Industrial Internet of Things (IoT or IIoT). Many organizations and companies have developed local taxonomies and categorization (devices, and IoT applications) for their own use. They may be labels (RFID) to identify goods and services in mass production, wear-able computers, structures located in smart homes or cities. It should be assumed that cases of IoT/IIoT use can extend to nearly every aspect of production (fig. 3). The result will be a decisive increase in the amount of data generated and processed. As the number of devices connected to the Internet increases, network traffic is expected to increase.

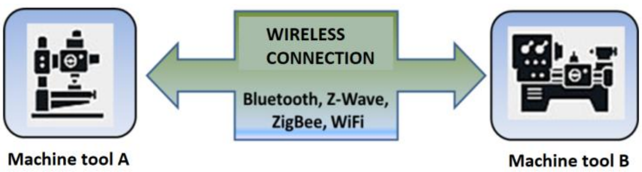

Fig. 3. Concept of cooperation (M2M) of technological machines

Cisco estimates that Internet traffic generated by non-PC devices will grow from 40% in 2014 to 70% in 2019. It also predicts that machine-to-machine (M2M), home, healthcare, Automotive and other IoT/IIoT applications will grow from 24% in 2014 to 43% in 2019 [3].

Many researchers underline the key role that the IIoT concept will play in the near future [4]. One of the key benefits is to get a very detailed description of all stages of production, which can be particularly important in the case of emerging deficiencies, breakdowns, determining actual expenditures and costs, or seeking sources of savings in the future. Up to date, only a small group of companies is ready to effectively implement IIoT into their environment.

There are four main areas of difficulty involved in implementing this concept:

- selecting the initial stage of the technological process from which the introduction of the IIoT concept into the plant's production environment begins,
- failure to adapt existing communication systems to transmit more data and rigid connection topology,
- commonly used centralized characteristics of automation products,
- difficulties in developing universal programming environments allowing for effective software development of IIoT components.

It is noteworthy that manufacturers increasingly identify their products as "active communicators", emphasizing their ability to work with modern digital data transmission systems.

Digital, i.e. smart factory

The concept of a modern digital factory is based on the full implementation of three main modules:

- complete integration of a computerized machine (connected factory), which effectively combines even individual machine tools and machine tools with superior enterprise management structures to create, store and process relevant information that actually describes the current state of production, in a virtual reality environment, to facilitate feasibility analysis and cost estimation of an order,
- interactive collaboration (collaborative factory – interactive), enabling the use of new generation (cooperative) robots, which should result in the combination of human intuition, flexibility, knowledge and adaptability with exceptional accuracy, repeatability, speed, power and autonomy of machines,
- intelligent management (smart factory – intelligent) by applying new algorithms and advanced processing of large (aggregate/precise) data, introducing efficient failure/failure forecasting, manufacturing process improvements, easy customization of products to specific customer requirements, full production tracking, resources, energy consumption and production waste.

The digital factory of the future also influences the change of classic, well-established communication models, resulting in complete modernization. The classic pyramid automation model (existing for more than 20 years) consists of well-defined layers arranged in such a way that information flows upwards – from the executive devices to the enterprise management structure (on the level of control, supervision and management). Although this model is well established, it is important to admit that data flow is not efficient [5]. In each of the layers of the present pyramid, there are various functional requirements, which led to the development of task-specific communication methods (standards and protocols). This issue is especially acute on the lower floor of the model (at the control level of technological devices). It requires real-time communication and compliance with stringent security requirements. The lack of a uniform standard of communication has led to the emergence of numerous competing protocols. The result is incompatibility not only inside but also between layers. Automation devices often support several different industrial protocols only to meet end-user demands, such as the MRP class system.

This is not in line with the idea of an open information architecture proposed in Industry 4.0. A new approach is needed to the problem of efficient data exchange. Modular information structure is a prerequisite for creating flexible, adaptive and intelligent production systems. Fig. 4 shows changes occurring in the industrial communication systems of industrial plants.

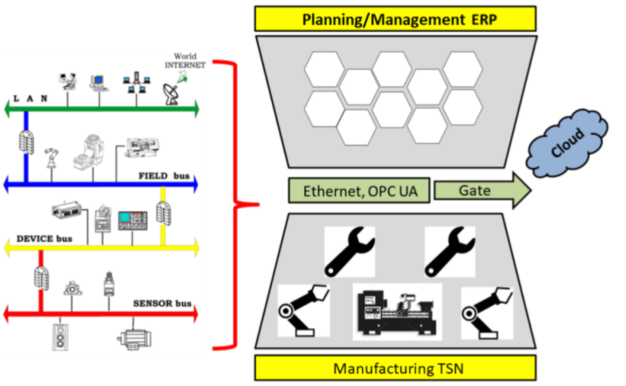

Fig. 4. Evaluation of the automation pyramid in the direction of YoYo [6]

Flattening of the existing structure of the pyramid (now resembling classic YoYo) is clearly visible. This is due to the increasing use of the popular Ethernet standard for data transmission, also in environments requiring real-time systems (control, monitoring, supervising). The TSN (time-sensitive networking) (IEEE 802.1Q) concept also enables efficient data exchange between the executive devices that make up the machine's components. The TSN standard consists of many components. For example, synchronization of packet transmission times, route planning, network reconfiguration, etc. For information not required to meet such stringent conditions (reporting, planning, management), more and more of the well-known OPC UA (united architecture), also using an Ethernet standard, is becoming increasingly popular. Recent implementations allow for data exchange in publication/subscription mode and support all computing technologies in computing clouds. It should be thought that such a concept will be increasingly popular in industrial environments in the coming years.

Information safety

Introduction of effective digitization of production is directly related to the creation, processing and transmission of vast amounts of data detailing the processes being carried out. Such information often includes descriptions of unique technologies, company secrets or machine park data. This represents a potential, serious threat to their interception or unauthorized access (e.g. competing companies). The issues of security of communication and access to enterprise IT systems are so significant that specialized devices, programs or even environments for the protection of confidentiality and data integrity are increasingly emerging in the market.

The primary threats to the digital factory are following:

- social engineering and phishing – countermeasures include: securing electronic correspondence, hindering unrestricted access of employees to unsafe or potentially suspicious areas of the Internet,
- malware – prevention: blocking the use of portable storage and media, encoding the contents of relevant files,
- remote maintenance access – prevent: drivers themselves or industrial PCs from restoring system software, installing additional software, sending technical reports without authorizing responsible operators, supporting VPN (virtual private network) connections,
- human errors or sabotage – counterfeiting: the introduction of password systems and the need for authorization of activities undertaken by operators and IT staff, training and enforcement of access rights, use of physical blocking of access to network equipment,
- direct Internet access – countermeasures: examining the state of the network for unprotected (free) drivers and computers, creating hardware and software barriers, demilitarizing zones, using trusted programs,
- technical malfunction – counteracting: permanent updating of internal firmware, automatic hardware diagnostics,
- wireless communication – countermeasures: limiting power and range of radio connections, shielding, encrypting transmissions, securing groups of devices,
- use of cloud computing applications – counteracting: limiting the outsourcing of sensitive data processing to external companies, creating encrypted connections,
- use of smartphones in industrial environment – counteracting: creation of mobile applications with limited functionality, strict supervision of mobile devices connected to the company network,
- distributed denial of service attacks (DoS): preventing: constant monitoring of hardware interfaces at DMZ boundaries, blocking of unused communication ports.

There are usually two separate issues: the safety of industrial networks in the workshop/machine room and the security of IT networks. These issues are perceived by manufacturers of industrial automation equipment and software. An example of this is the entire Siemens range. Fig. 5*a* shows specially developed, secure, hardware communication processors (Scalance M872-2). Phoenix Contact also offers devices for enterprise network communications, such as intelligent/managed Ethernet switches (fig. 5*b*).

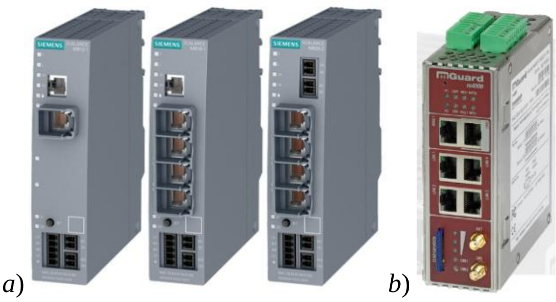

Fig. 5. Scalance family of processors [7] (*a*); Phoenix Contact mGuard rs4000 4TX/3G/TX VPN Switch [8] (*b*)

Machine and process monitoring

Based on the idea of Industry 4.0, the need to collect detailed and up-to-date data describing the state of the manufacturing process and the individual machines has been noted by manufacturers of controllers and automation components. The source of information may be measurements of force, pressure, temperature, speed of movement, speed, frequency, momentum, stress, vibration, current, voltage and other [9]. Due to the multitude of measuring systems, the logical direction of the manufacturers' activities is to prepare the universal measuring systems to maximize automation of the measurement environment. Specialized modules are available for downloading various sensor data, which can be easily added to the control structure of the machine tool – also in control systems of already operating machines.

An example of this may be the Beckhoff family of products (ELM 36xx and 37xx). The PLC/PAC module (fig. 6) is equipped with four independent measuring channels with 24-bit analog-to-digital converters. The maximum sample rate allows you to collect 50,000 samples/sec. Constant synchronization with internal or master calibration clock in the time window below 1 μs is assured. Accurate measurement accuracy is better than 100 ppm (parts per million), meaning less than 0.01%. In order to facilitate the creation and operation of the measurement system, special software packages (for monitoring, analytics, visualization, interactive graphs) are included. They include ready-made digital filter libraries, as well as modules for determining correction factors and rapid spectral analysis and other analyzes, which greatly accelerates and facilitates designers' work. All data may be available to external measurement and analytical programs, as the TwinCat development environment supports cloud computing and the Internet of Things.

Fig. 6. Beckhoff universal measurement modules [10]

Fig. 7. Ahlborn Almemo 710 mobile measurement module [11]

Another example of creating advanced measuring systems for use alone or as part of an operating technology machine is the Ahlborn product. The Almemo 710 (fig. 7) is a universal data acquisition system. Allows simultaneous connection of 10 different analog signal sources. Each channel can store up to 100 samples per second. Built-in rechargeable batteries allow independent operation of fixed power sources for many hours (power consumption in the sleep mode is 0.05 mA). Data can be transferred to the host system (USB or Ethernet) and analyzed or presented on the built-in LCD screen.

The natural direction of action is the direct sharing of data from IIoT systems to applications running in the cloud. The most promising are universal devices, which allow the transfer of information from the machine tool to the Internet. This is the function of network gateways. An example is the DataEagle 7050 from Schildknecht (fig. 8). The device can work with any local network of any standard. Data is transmitted via packet transmission using wireless telephone networks in each of the world's existing standards (2G, 3G, 4G, 5G). The internal compression and encryption mechanisms allow encoding information and sending them directly in one of the selected protocols (OPC UA, Reest API, MQTT, XML, SMS, Twitter, FTP, Mail), which reduces the calculation cloud load.

Fig. 8. Intelligent data transmitter IoT/Cloud of Schildknecht DataEagle 7050 [12]

Having detailed and up-to-date data about the machine tool used in the process can effectively influence the existing relationship between the user and the machine manufacturer. Currently, corrective actions are taken after a malfunction has occurred or only after a malfunction has occurred. The long-term goal is to change the traditional relationship and establish an active contact between the user, the manufacturer and the machine tool constructor, so as to prevent damage that requires the machine to be shut down.

Such a philosophy of action is promoted by Weidmüller. A special software (Advanced Analytics) is proposed to monitor machine condition and to anticipate possible problems – fig. 9. However, this is not an easy task. Nowadays, thanks to the installation of more and more sensors, a lot of information (temperature, pressure, energy consumption, vibration) is available. This results in more and more data being generated.

The most important action is the proper processing of data (omitting irrelevant or redundant phenomena) to obtain really valuable information. One of the concepts is to look for machining behavior patterns, which is the basis for understanding the proper behavior of the machine during machining and enabling the model to be developed. If the data acquired on an ongoing basis differs from the adopted model, this means anomaly. If this anomaly is repeated, it probably means an error. By following this procedure, it is possible to anticipate the condition of the machine and allow users to take active measures to avoid a major accident. The strength of software programs that oversee the state of the machine tool or process is the ability to skillfully filter and perform advanced analysis of selected information.

Fig. 9. Weidmüller advanced data analysis concept [13]

Collaborative robots

Contemporary production, or virtually ubiquitous on the market, requires a shorter product lead time, a flexible approach to customer requirements, a personalized production offer, the highest quality of the product, and at least a moderate price. So varied criteria force a change in the traditional understanding of the concept of manufacturing as a sequence of separate activities performed by workers, machine tools, transport systems and robots.

We are witnessing a breakthrough in robotics. Starting with the separate areas (cells), where robotic systems were originally installed (protected against accidental contact with humans), through coexistence (shortening distance), synchronized work, to a contemporary strategy, i.e. free, unrestricted co-operation. Such states may be offered by collaborative robots (cobots). Their design, however, must take into account the specific requirements of human presence in the field of the robot. These are: full control of the force and dynamics of the motion of the arms, with the delicacy of movement and precision depending on the situation. In the event of a collision, the system must not pose any risk to the worker, especially since the operator is not separated as in the case of conventional robots. One of the lines of action that allows these requirements to appear is the use of motion sequences and the design of kinematics of robots co-operating according to intuitive human action. The result of this action is the proposal of Festo – BionicCobot (fig. 10).

Fig. 10. Bionic-Cobot – a collaboration robot produced by Festo [14]

The design is modeled on human hands, starting from the top of the arm through the elbow up to the wrist and gripping part of the palm. Traffic energy provides compressed air. A pressure sensor and absolute encoder are installed in each joint. Measurements and control signals are transmitted via the CAN bus, providing full real-time control. Robot control is performed using a specially developed ROS (robot operating system), which works in graphical format and is an interface of the FMS environment (Festo Motion Terminal). It makes the necessary kinematic calculations, and it measures the pressure and air volume, freeing the operator from the need to control the sequence of movements. It is also possible to work in learning mode.

Another interesting product of this company is the special grip referring to the octopus arm (OctopusGripper, fig. 11). It consists of a set of soft silicone components controlled by compressed air. Standard parameters are: length 22 cm, weight 190 g, working air pressure 2 bar. When the air is supplied, the flexible suction cup bends inwards and can wrap the grip in the correct position. The clamping force is large enough to hold an element in this position, but does not cause it to permanently deformation.

Fig. 11. Flexible gripper OctopusGripper produced by Festo [15]

In the field of traditional robots, Igus has presented an interesting concept for a cheap and easy to implement robot (transportable arm) for transport and handling purposes (fig. 12). The concept is based on the application of simple and flexible elements in the offer of this company. Individual components of the articulated arm do not require lubrication or any maintenance work. The multitude of options available allows you to freely shape the kinematic structure of the robot. Presented robot in the most advanced version offers five-axis freedom of manipulation and maximum lifting capacity up to 8 kg. The proposed price is 3,200 euros for mechanics and drives and 5,000 euros for the version with dedicated Commonplace Robotics (CPR) control system. The robot can be supervised and controlled using a regular tablet.

Fig. 12. Modular robot manufactured by Festo [16]

Wired Ethernet

In the Industry 4.0 concept, a key position is the acquisition of detailed data on equipment, machinery and process. The basic means of transmission are traditional wired media offering reliability, speed and high bandwidth. New materials and production technologies also allow them to be used where there is displacement or movement (fig. 13). As an example, the Lapp product can be used, according to the manufacturer's data, a new Ethernet Category 7 Ethernet cable (6.4 mm diameter) for 10 Gbit/s data transfer with mechanical strength of 5 million twists at ±180° with a cable length of 1 m. The thermal resistance allows it to be used in the temperature range of -40 to 105 ° C. The cable sheath is resistant to aggressive oil and gasoline environments. Such wide tolerances make the cable suitable for a wide range of applications without the need for a sheath, making it easier to carry and reduce costs.

Fig. 13. Modern Ethernet cable (category 7) for industrial environments [17]

Conclusions

The idea of Industry 4.0 is not an end in itself. It is primarily a means of creating new products with greater diversity, functionality and attractiveness for users while reducing emissions, waste and energy consumption. These requirements directly affect the form of modern IT communication in the industry. It is important to note, however, that there is still a big difference between the proposed latest concepts and the ideas of machinery and technology, and the real diffusion and use of them in existing halls and production workshops. The described directions of development are as real as possible, but their implementation will have to wait.

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